Monitoring the levels of radon and toxic elements pollutants in bottled drinking water

B.A. El-Badry^{1,2}, T.I. Al-Naggar^{1,3,4*}, G.A. Khouqeer²

¹Department of Physics, College of Women, for Arts, Science, and Education, Ain-Shams University, Cairo, Egypt ²Department of Physics, College of Science, Al-Imam Mohammad Ibn Saud Islamic University (IMSIU), P.O. Box 5701, Riyadh 11432, Saudi Arabia

³Department of Physics, College of Science and Arts, Najran University, P.O. Box 1988, Najran 11001, Saudi Arabia ⁴Unit of Radiation Protection, Najran University, Najran1101, Saudi Arabia

ABSTRACT

▶ Original article

*Corresponding authors: Tayseer I. Al-Naggar, Ph.D.,

E-mail: ty_sab_sy@yahoo.com

Revised: August 2019 **Accepted:** September 2019

Int. J. Radiat. Res., July 2020; 18(3): 427-435

DOI: 10.18869/acadpub.ijrr.18.3.427

Background: The existence of radioactive isotopes and toxic elements in water poses a potential threat to public health. Due to the high consumption of bottled water, the focus of this study is on measuring the concentration of radioactive isotopes (222Rn and 226Ra) and toxic elements (Cr, Mn, Co, Ni, Cu, Zn, Cd, Pb) in different brands of bottled drinking water. Materials and Methods: Therefore, twenty-four samples of bottled water have been carefully selected from local markets in Saudi Arabia. Nuclear track detector of type CR-39 and Inductive Coupled Plasma-Mass Spectrometer were used to measure radioactivity concentrations and toxic elements, respectively. Results: It is observed that the activity concentration of ²²²Rn and ²²⁶Ra in all samples was lower than the recommended values set by different agencies such as WHO, and EPA. The annual effective dose for three age groups (infants, children, and adults) was calculated from the concentration of ²²²Rn. These measurements provide basic information for consumers who could be at risk of exposure through bottled water consumption. Conclusion: then all types of bottled drinking water are suitable and safe for daily population ingestion.

Keywords: Bottled drinking water, radon, toxic elements, CR-39, inductive coupled plasma-mass spectrometer.

INTRODUCTION

Water has many different and varied benefits to humans. The average amount that a person needs to drink is eight and ten cups per day. Therefore, its quality is of great importance to human health and it must be free from any toxic natural radioactive elements. elements such as chromium (Cr), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), arsenic (As), manganese (Mn), cadmium (Cd), lead (Pb), and mercury (Hg), and radioactive materials such as uranium, thorium and their decay products (radium, and radon) have several impacts on human (1,2). The radiation released from radium could affect tissues in the bone marrow which could cause a bone tumor. During the decay of radium, radon gas is formed. Long exposure time to radon and its daughters will cause health changes in respiratory functions which may lead to lung cancer (3). In addition, a large amount of radon in drinking water may cause a substantial risk such as stomach and gastrointestinal cancer (4). Therefore, measurement of radium, and radon concentration in water is important from the radiological perspective. The Environmental Protection Agency (EPA) and World Health Organization (WHO) have developed a standard level of 11 Bq/L and 100 Bq/L for drinking water, respectively (5,6). Furthermore, it has been given that the annual effective dose produced by radioisotopes of radon in drinking water is 0.1 mSv/y (6,7). CR-39 is one of the most reliable detectors that are widely used in 222Rn

measurement and belongs to etched nuclear track detectors (ENTDs). CR-39 polymer detectors are made from allyl diglycol carbonate monomer and its chemical formula C₁₂H₁₈O₇ ⁽⁸⁾. The pollution of drinking water with toxic metals is a substantial threat to society and the environment. The amount of the toxic metals that are absorbed by the digestive system varies greatly depending on the chemical structure of the metals, the age of the individual and the nutritional status. Once a toxic metal is absorbed, it spreads itself in organs and tissues. The excretion process occurs mainly through the kidney and digestive system. However, metals tend to stay in some storage areas, such as the kidney, liver, and bones for years (9). The kidneys are the first target organs affected by metal toxicity, in addition, other infections may occur (10). Therefore, a high level of toxic metals in bottled drinking water may have detrimental side effects. Many studies have been submitted on natural radioactivity and toxic elements concentration in water in several countries (11-18). Due to the large consumption of bottled drinking water this research focuses on determining the natural radioactive and toxic elements concentration in different brands of bottled drinking water currently consumed in Saudi Arabia, using CR-39 nuclear track detector Inductive Coupled Plasma-Mass Spectrometer, respectively. Also, estimating the radiological risk resulting in the human using the water in this region.

MATERIALS AND METHODS

Different types of bottled drinking water samples were selected from the local markets in Saudi Arabia. Twenty-four samples of bottled drinking water were collected from (Nova, Hana, Safa Makah, Mawared, Berain, Aquafina, Nestle, and Al-Qassim) types. According to table 1, three samples of each type of bottled drinking water were analyzed by placed it in a plastic flask with 5 cm radius and 15 cm height as shown in figure 1. A Sheet of CR-39 detector was cut into pieces of 1 cm² and pasted at the bottom of the plastic

lid per flask. The lid was closed tightly to ensure that there are no outlets for alpha particles emitted from 222Rn. One flask without water sample was used as a reference to calculate the background radiation. The flasks were left for six months to ensure that the equilibrium was reached between radioactive isotopes (19). After exposure time all detectors were collected together and etched by NaOH solution with normality of 6.25 N at 70 °C for 7h using water bath technique (8). The number of alpha tracks can be observed after the etching process using an optical microscope with magnification 400X. Toxic elements namely Cr, Mn, Co, Ni, Cu, Zn, Cd and Pb in bottled drinking water samples were measured with Inductive Coupled Plasma-Mass Spectrometer. (ICP-MS) Thermo scientific, Instrument at Central Laboratory College of Science (CLCS) King Saud University, Riyadh, KSA. The external calibration was carried out using multi-element standard of the ultra-scientific analytical solution. Each sample was analyzed in three replicates. In this study all data were analyzed using statistical program "SPSS program" with using appropriate statistical tests described in results section. P value < 0.05 was considered as significant level.

RESULTS AND DISCUSSION

Radioactivity analysis

Concentration levels of ²²²Rn and ²²⁶Ra were assessed for twenty-four samples from different local bottled drinking water brands commercially consumed in Saudi Arabia, which are recorded in table 1. Table 1 shows that the activity concentration range of ²²²Rn in Nova, Hana, Safa Makah, Mawared, Berain, quafina, Nestle and Al-Qassim bottled drinking waters. This study shows that the concentration of ²²²Rn are lower than WHO action level of 100 Bql-1 in all water brands (20), and also lower than EPA action level of 11 Bql-1 (21). The results show variation in radioactivity concentration of ²²²Rn and ²²⁶Ra in all the bottled water brands, this may be due to radioactivity in bottled water is based on various parameters such

geochemistry of origin isotopes, the interaction among water and rigid juncture with which it reaches into friction through its period during the terrestrial crust ^(22,23). According to WHO guidelines, the activity concentration of ²²⁶Ra in all bottled drinking water are within the WHO action level 1 Bql⁻¹ ⁽⁷⁾. Figure 2 displays the comparison between the activity concentration for both ²²²Rn and ²²⁶Ra. It is observed that in all samples the concentration of ²²²Rn was lower than those from ²²⁶Ra. ²²⁶Ra appears with a high concentration in all samples due to the location of the main source of the water. The common

main source of bottled water is deep aquifers that have been in longer contact with the host rock of the aquifer than shallow ground water or spring water (24,25). By comparing our results for radon concentrations in this study with the data of other studies for different sites in the world. It's clear that, the range of radon concentration in bottled water in this study was lower when compared to the values reported in Austria, Kuwait, Egypt, and Serbia (26,27,32,33), and was higher than the values reported in Iran, Brazil, Thailand, and Iraq (28-30,31) as shown in table (2).

Table 1. Activity concentrations of ²²²Rn, and ²²⁶Ra in bottled drinking water samples.

Sample	Sample	Sample	Rn-222	Ra-226
No	source	Code	(Bq/L)	(Bq/L)10 ⁻³
1	Nova1	N1	1.15±0.002	1.45±0.002
2	Nova2	N2	1.23±0.014	1.56±0.020
3	Nova3	N3	1.45±0.059	1.83±0.076
4	Hana1	H1	1.49±0.067	1.88±0.086
5	Hana2	H2	1.31±0.031	1.65±0.039
6	Hana3	Н3	1.89±0.149	2.39±0.190
7	SafaMakah 1	S1	0.67±0.100	0.85±0.125
8	Safa Makah2	S2	0.96±0.041	1.22±0.049
9	Safa Makah 3	S 3	1.10±0.012	1.39±0.014
10	Mawared1	M1	1.03±0.027	1.30±0.033
11	Mawared2	M2	0.93±0.047	1.18±0.057
12	Mawared3	М3	0.89±0.055	1.12±0.069
13	Berain1	B1	0.46±0.143	0.58±0.180
14	Berain2	B2	0.80±0.073	1.01±0.092
15	Berain3	В3	0.62±0.110	0.79±0.137
16	Aquafina1	A1	0.41±0.153	0.52±0.192
17	Aquafina2	A2	0.48±0.139	0.61±0.174
18	Aquafina3	A3	0.57±0.120	0.72±0.151
19	Nestle1	E1	1.85±0.141	2.34±0.180
20	Nestle2	E2	2.11±0.194	2.67±0.247
21	Nestle3	E3	2.46±0.265	3.11±0.337
22	Al-Qassim1	Q1	1.60±0.090	2.02±0.114
23	Al-Qassim2	Q2	1.18±0.004	1.49±0.006
24	Al-Qassim3	Q3	1.13±0.006	1.43±0.006

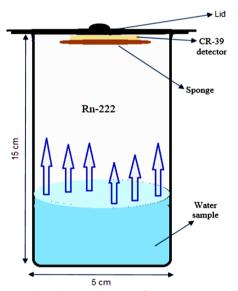


Figure 1. Closed-can technique of radon measurements.

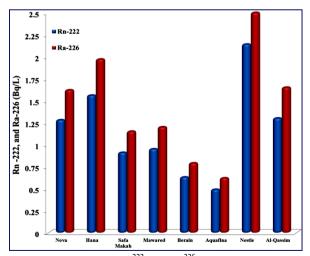


Figure 2. Distribution of ²²²Rn, and ²²⁶Ra in bottled drinking water.

El-Badry et al. / Levels of radon and toxins in drinking water

Table 2. Comparison concentration of Rn-222 in bottled waters with different sites in the world.

Country	Source of water	Rn-222 (Bq/L)	References	
Saudi Arabia	Bottled drinking water	0.41- 2.46	Present work	
Austria	Bottled drinking water	0.12–18	(26)	
Serbia	Bottled drinking water	0.91-1463	(27)	
Thailand	Bottled drinking water	0.2-0.3	(28)	
Brazil	Bottled drinking water	0.1	(29)	
Iran	Bottled drinking water	0 – 0.90	(30)	
Iraqi	Bottled drinking water	0.0354 - 0.248	(31)	
Kuwait	Bottled drinking water	1.02 - 6.05	(32)	
Egypt	Bottled drinking water	0.93 - 6.89	(33)	

Statistical analysis

Table 3 displays the descriptive statistics of activity concentrations for ²²²Rn, and ²²⁶Ra in (Bq/L) for twenty-four samples of bottled drinking water. Descriptive statistics have elementary statistics (mean, median, variance, std. deviation, skewness, kurtosis, etc.) of a group of data. The mean, median, std. deviation, variance, skewness, kurtosis of activity concentrations of ²²²Rn are 1.1571 Bql-1, 1.1150

Table 3. Descriptive Statistics of ²²²Rn, and ²²⁶Ra in (Bg/L).

Descriptive Statistics	Rn-222 (Bql ⁻¹)	Ra-226 (Bql ⁻¹)						
Mean	1.1571	2.9575						
Median	1.1150	2.8500						
Std. Deviation	0.54082	1.3811						
Variance	0.292	1.907						
Skewness	0.699	0.706						
Std. Error of Skewness	0.472	0.472						
Kurtosis	0.080	0.092						
Std. Error of Kurtosis	0.918	0.918						
Range	2.05	5.23						
Minimum	0.41	1.06						
Maximum	2.46	6.29						
One-Sample Kolmogorov-Smirnov Test								
Kolmogorov-Smirnov Z	0.554	0.506						
Asymp. Sig. (2-tailed)	0.919	0.960						

Bgl-1, 0.54082 Bgl-1, 0.292 Bgl-1, 0.699, and 0.080 respectively. In addition, for 226Ra they are 2.9575 Bql-1, 2.8500 Bql-1, 1.3811 Bql-1, 1.907 Bql ⁻¹, 0.706, 0.092, respectively. Figures 3 and 4 display normal distributions for histogram of activity concentrations for ²²²Rn, and ²²⁶Ra, this normality of frequency distributions for both radioactive isotopes ²²²Rn and ²²⁶Ra are indicated by two parameters; One-Sample Kolmogorov-Smirnov test, and the values of the kurtosis. The first one has many applications such as commerce processes, environmental analysis, and production suppose suitable normality of data is ordinarily established using tests of normality (37, 35). Kolmogorov Smirnov test was applied on the current data of the activity concentrations of 222Rn, and 226Ra using SPSS statistical program. Asymp. Sig (p-values) are 0.919, and 0.960 for 222Rn, and 226Ra respectively, both p-values > 0.05 which means the data of the concentration of ²²²Rn, and ²²⁶Ra follows the Poisson distribution as shown in figures 3 and 4 (35,36). The second parameter, which indicates the Gaussian distribution is the value of the kurtosis. The q-kurtosis of activity concentrations of 222Rn, and 226Ra are 0.080, 0.092 respectively, since q-kurtosis is finite in the range of $0 \le q < 3$, this range of q-kurtosis is sufficient to refer for q-Gaussian distributed data sets as one does in the standard definition of the kurtosis (37,38).

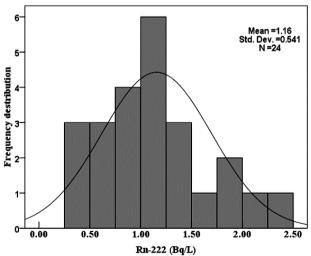


Figure 3. Frequency distribution of activity concentration of ²²²Rn (Bq/L).

Int. J. Radiat. Res., Vol. 18 No. 3, July 2020

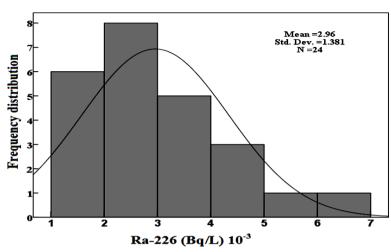


Figure 4. Frequency distribution of activity concentration of ²²⁶Ra (Bq/L).

Contribution of ingestion annual effective dose

The ingestion annual effective doses for the individuals resulting from the 222Rn concentration in different drinking water samples among different types of age groups (infants (1-2 y), children (7-12 y) and adults (>17 y) are summarized in table 4. It is safe to assume that Nova, Hana, Safa Makah, Mawared, Berain, Aquafina, Nestle, and Al-Qassim were the main sources of bottled drinking water of types for daily water consumption in Saudi Arabia. Table 4 gives the mean annual effective dose due to ingestion of 222Rn in drinking water for infants, children and, adults respectively. Figure 5 illustrates contribution of each type of bottled drinking water to the total ingestion annual effective dose due to 222Rn among different types of age groups. The percent contribution dose due to ²²²Rn for the infant age group can be ordered as follows; Nestle > Hana > Nova, and Al-Qassim > Safa Makah, and Mawared > Berain > Aquafina. The Nestle bottled water has an ingestion effective dose of 23% from the total dose percentage while the Aquafina bottled water has a lower contribution of 5% from the total dose percent. The contribution dose for children age group can be ordered as follows; Nestle > Hana, Nova, and Al-Qassim > Safa Makah, and Mawared > Berain, and Aquafina. For children age group the Nestle water has an ingestion effective dose of 25% from the total dose percent while two other bottled drinking water brands, Berain and Aquafina, have a lower contribution of 5% from the total dose percent. The contribution dose for adult's age group can be ordered as follows; Nestle > Hana > Al-Qassim > Nova > Mawared and Aquafina > Safa Makah, and Berain. For adult age group, the Nestle water has the ingestion effective dose of 25% from the total dose percent, while three other bottled drinking water brands, Safa Makah, and Berain, have a lower contribution are 8% from the total dose percentage. From the current analysis of data of ingestion dose, all values of annual effective dose for all types of bottled drinking water due to ingestion of ²²²Rn for three different age groups (infants, children and adults) are lower than the recommended value of 0.1 mSvy-1 (7, 39).

Toxic elements analysis

The results of toxic elements analysis using inductive Coupled Plasma-Mass Spectrometer for bottled drinking water are concluded in table 6, along with the worldwide standard levels. Figure 6 shows the average concentration of toxic elements is ordered as Zn > Cr > Pb > Ni > Cu > Cd > Co > Mn, and all toxic elements concentrations are lower than the Action levels of WHO organization (7) as seen in table 5. The relation between radon concentrations and toxic elements were produced in figure 7a to 7g. All relations have poor negative correlations between ²²²Rn and all toxic elements in all types drinking bottled water, these poor

El-Badry et al. / Levels of radon and toxins in drinking water

correlations may be due to various geochemical behavior for radon and toxic elements (40, 41).

Physicochemical parameters

Table 7 shows the physicochemical parameters in different brands of bottled drinking waters. All physicochemical parameters such as TDS, PH, K, Na, Mg, Ca, Fe,

Nitrates, fluorides, Chlorides, SO_4 , and HCO_3 were consistent with the permissible levels according to different agencies like WHO, EU ⁽⁴²⁾, and FDA ⁽⁴³⁾ in these bottled water samples. Hence, all bottled drinking water brands which were analyzed in this work are safe, and proper for human intake.

Table 4. Annual effective dose (mSv/y) due ²²²Rn concentration in different brands of bottled water.

Sample	Sample Sample Annual effective dose (mSv/y)						
No	source	code	Infant	Children	Adult		
1	Nova1	N1	6.07 ± 0.010	2.23 ± 0.004	2.93 ± 0.006		
2	Nova2	N2	6.53 ± 0.083	2.40 ± 0.031	3.15 ± 0.039		
3	Nova3	N3	7.67 ± 0.316	2.82 ± 0.116	3.71 ± 0.153		
4	Hana1	H1	7.86 ± 0.355	2.89 ± 0.131	3.80 ± 0.171		
5	Hana2	H2	6.92 ± 0.163	2.55 ± 0.061	3.34 ± 0.078		
6	Hana3	Н3	9.98 ± 0.788	3.67 ± 0.290	4.82 ± 0.380		
7	Safa Meka1	S1	3.55 ± 0.525	1.31 ± 0.192	1.72 ± 0.253		
8	Safa Meka2	S2	5.09 ± 0.210	1.87 ± 0.078	2.46 ± 0.102		
9	Safa Meka3	S3	5.81 ± 0.063	2.14 ± 0.022	2.81 ± 0.031		
10	Mawared1	M1	5.45 ±0.137	2.01 ± 0.049	2.63 ± 0.067		
11	Mawared2	M2	4.92 ± 0.245	1.81 ± 0.090	2.38 ± 0.118		
12	Mawared3	M3	4.70 ± 0.290	1.73 ± 0.106	2.27 ± 0.141		
13	Berain1	B1	2.44 ± 0.751	0.90 ± 0.276	1.18 ± 0.363		
14	Berain2	B2	4.22 ± 0.388	1.55 ± 0.143	2.04 ± 0.188		
15	Berain3	В3	3.30 ± 0.576	1.21 ± 0.212	1.59 ± 0.280		
16	Aquafina1	A1	2.19 ± 0.802	0.80 ± 0.296	1.06 ± 0.388		
17	Aquafina2	A2	2.56 ± 0.727	0.94 ± 0.267	1.24 ± 0.351		
18	Aquafina3	А3	2.99 ± 0.639	1.10 ± 0.235	1.44 ± 0.310		
19	Nestla1	E1	9.79 ± 0.749	3.60 ± 0.276	4.73 ± 0.361		
20	Nestla2	E2	11.17 ± 1.031	4.11 ± 0.380	5.40 ± 0.498		
21	Nestla3	E3	13.02 ± 1.408	4.79 ± 0.518	6.29 ± 0.680		
22	Al-Qassim1	Q1	8.46 ± 0.477	3.11 ± 0.176	4.09 ± 0.231		
23	Al-Qassim2	Q2	6.24 ± 0.024	2.30 ± 0.010	3.01 ± 0.010		
24	Al-Qassim3	Q3	5.98 ± 0.029	2.20 ± 0.010	2.89 ± 0.014		

Table 5. Mean of annual effective dose (mSv/y) due to ²²²Rn ingestion for three groups of age (Adult, children, and infant) in different types of bottled drinking water.

	• • • • • • • • • • • • • • • • • • • •	_						
Matartuna	Mean of annual effective dose (mSv/y) 10 ⁻³							
Water type	Adult	Children	Infant					
Nova	6.75 ± 0.14	2.49 ± 0.05	3.26 ± 0.07					
Hana	8.25 ± 0.44	3.04 ± 0.16	3.99 ± 0.21					
Safa Makah	4.82 ± 0.27	1.77 ± 0.10	2.33 ± 0.13					
Mawared	5.02 ± 0.22	1.85 ± 0.08	2.43 ± 0.11					
Berain	3.32 ± 0.57	1.22 ± 0.21	1.60 ± 0.28					
Aquafina	2.58 ± 0.72	0.95 ± 0.27	1.25 ± 0.35					
Nestle	11.33 ± 1.06	4.17 ± 0.39	5.47 ± 0.51					
Al-Qassim	6.89 ± 0.18	2.54 ± 0.07	3.33 ± 0.09					

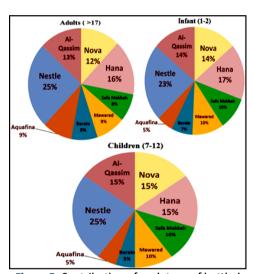


Figure 5. Contribution of each type of bottled water to the total ingestion annual effective dose due to ²²²Rn among different types of age groups.

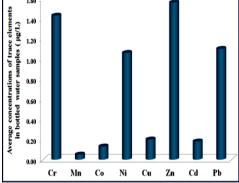


Figure 6. Average concentration of trace element $(\mu g/L)$ in different brands of bottled drinking water.

Table 6. Concentrations of trace element (μg/L) in different brands of bottled drinking waters, and worldwide standard levels.

No	Water type	Cr	Mn	Со	Ni	Cu	Zn	Cd	Pb
1	Nova	2.34 ± 0.08	0.23 ± 0.05	0.41± 0.05	1.51 ± 0.05	0.35±0.04	1.61 ± 0.18	0.76 ± 0.05	8.50±0.26
2	Hana	1.21 ± 0.30	0.00	0.05 ± 0.08	0.84 ± 0.06	0.16±0.10	1.10 ± 0.30	0.08 ± 0.01	0.00
3	Safa Makah	1.34 ± 0.087	0.04 ± 0.01	0.12 ± 0.02	1.14 ± 0.08	0.10 ±0.02	2.29 ± 0.11	0.10 ± 0.01	0.00
4	Mawared	1.87 ± 0.05	0.05 ± 0.02	0.08 ± 0.003	1.23 ± 0.13	0.16±0.04	2.05 ± 0.20	0.08 ±0.006	0.00
5	Berain	1.20 ± 0.11	0.00	0.06 ± 0.004	0.86 ± 0.02	0.34±0.11	0.99 ± 0.24	0.10 ± 0.01	0.30±0.01
6	Aquafina	1.02 ± 0.03	0.07 ± 0.02	0.07 ± 0.01	0.80 ± 0.05	0.00	1.07 ± 0.04	0.08 ± 0.01	0.00
7	Nestle	1.25 ± 0.20	0.00	0.10 ± 0.03	0.91 ± 0.13	0.24±0.10	1.67 ± 0.25	0.10 ± 0.02	0.00
8	Al-Qassim	1.21 ± 0.40	0.03 ± 0.01	0.14 ± 0.04	1.15 ± 0.26	0.06±0.10	1.73 ± 0.46	0.10 ± 0.02	0.00
9	Average	1.43	0.05	0.13	1.06	0.20	1.56	0.18	1.10
10	Action level WHO	50	500	50	70	2000	3000	3	10

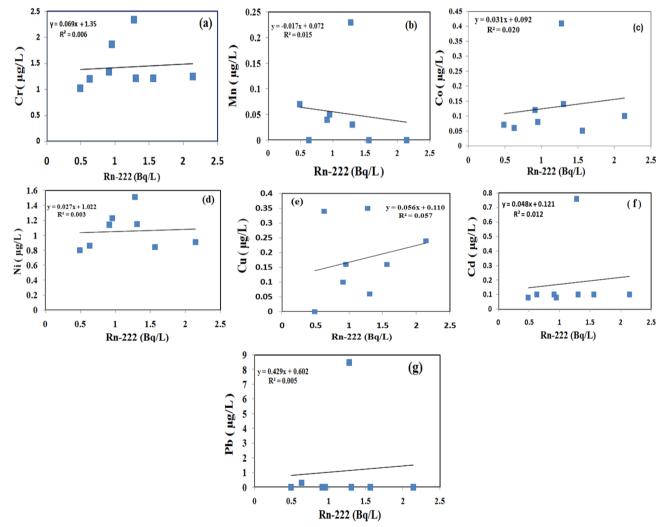


Figure 7. Relation between concentration of 222Rn and toxic elements in bottled drinking water: (a) Cr vs. Rn, (b) Mn vs. Rn, (c) Co vs. Rn, (d) Ni vs. Rn, (e) Cu vs. Rn, (f) Cd vs. Rn, (g) Pb vs. Rn.

El-Badry et al. / Levels of radon and toxins in drinking water

Table 7. Physicochemical parameters in different brands of bottled drinking water in mg/L	Table 7. Physicochemical	parameters in different	brands of bottled d	lrinking water in mg/L
--	---------------------------------	-------------------------	---------------------	------------------------

table 11. Ayona and parameters in an area and a souther a mining it area. In 187 =												
Water Type	TDS	PH	K	Na	Mg	Ca	Fe	Nitrates	fluorides	Chlorides	So ₄	HCO3 [−]
Nova	120	7.4	1.2	17	3.4	11	0	3	1	19	26	26
Hana	120	7.8	8	3	9	21	0	0.2	1	32	28	18
Safa Makah	110	7.2	0.20	13	1.5	12	0	0.04	1	26	7	28
Mawared	120	7.2	1.5	12.3	3	14.4	0	2	0.9	17.5	28	24
Berain	155	8	0.9	25	2	15	0.01	0.1	1.1	32	7	70
Aquafina	110	7	1	16	13	Less than 5	0.01	Less than 0.1	1	27.5	51	1.3
Nestle	120	7	0.2	9.5	2.3	27	Less than 0.02	Less than 1	0.8	50	10	22
Al- Qassim	140-180	6.85-7.4	1	25	2	12	0	5	0.95	35	25	10
Action level	500	7.0-9.2		200 mg/l	50	75-200 mg/l	0.2 ^b	10-40 ^c	1.5	300	250	50

a (WHO., 2011), b (EU., 2005), c (FDA., 1998)

CONCLUSION

The following bottled drinking water; Nova, Hana, Safa, Makah, Mawared, Berain, Aquafina, Nestle, and Al-Qassim are widely consumed in Saudi Arabia. Radioactivity analysis was done for all bottled drinking water samples providing additional evidence about the health risks. The activity concentration of 222Rn, and 226Ra was below the safe limits recommended by WHO organization in all the bottled drinking water tested. The annual effective dose of total ingestion for three different age groups (infants, children and adults) was assessed and the value for each age group was lower than the recommended value of 0.1mSv/y by WHO. The concentration of toxic elements physicochemical parameters were within the global levels according to different agents, and relations were found between radon concentrations and toxic elements, then all types of bottled drinking water are suitable and safe for daily population ingestion.

Conflicts of interest: Declared none.

REFERENCES

- 1. Hadiani MR, Dezfooli-Manesh S, Shoeibi S, Ziarati P, Mousavi KA (2015) Trace elements and heavy metals in mineral and bottled drinking waters on the Iranian market. *Food Additives & Contaminants, Part B, 8*: 18-24.
- 2. Naskar AK, Gazi M, Barman C, Chowdhury S, Mondal M, Ghosh D, Sinha B, Deb A (2018) Estimation of underground

- water radon danger in Bakreswar and Tantloi Geothermal Region, India. *Journal of Radioanalytical and Nuclear Chemistry*, **15**: 273-283.
- BEIR VI (1999) Report of the committee on the biological effects of ionizing radiation. Health effects of expose to radon. National research council, The National Academies Press, Washington.
- Kendal GM and Smith TJ (2002) Dose to organs and tissues from radon and its decay products. J Radiol Prot, 22: 389-406
- EPA US, Environmental Protection Agency (2015) International Decontamination Research and Development Conference, U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-15/283.
- WHO (2004) World Health Organization, Guidelines for Drinking Water Quality. Third ed., Geneva.
- WHO (2011) Guidelines for Drinking-water Quality FOURTH EDITION WHO Library Cataloguing-in Publication Data Guidelines for drinking-water quality-4_{th} ed, Geneva.
- EL-Badry BA and Al-Naggar TI (2018) Estimation of indoor radon levels using etched track detector. *Journal of Radia*tion Research and Applied Sciences, 11: 355–360.
- 9. Al-Nafiey MS, Mohammad SJ, Sabar B (2014) Measuring radon concentration and toxic elements in the irrigation water of the agricultural areas in Cameron highlands. *Malaysia*, *Sains Malaysiana*, *43(2)*: 227-231.
- Barbier O, Jacquillet G, Tauc M, Cougnon M, Poujeol P (2005) Effect of Heavy Metals on, and Handling by, the Kidney Olivier. Nephron Physiology, 99: 105–110.
- Tareen AK, Sultan IN, Parakulsuksalid SM, Khan A, Khan MW, Hussain S (2014) Detection of heavy metals from drinking waters of district Peshin, Balochistan, Pakistan. Int J Current Microbiol Appl Sci, 3: 299–308.
- Dark, G, Faanu A, Akoto O, Acheampong A, Goode EJ, Gyamfi O (2015) Distribution of natural and artificial radioactivity in soils, water and tuber crops. *Environmental Monitoring and Assessment*, 187(6): 1–11.
- 13. Althoyaib SS and El-Taher A (2016) Natural radioactivity levels of radon, radium and the associated health effects in drinking water consumed in Qassim area, Saudi Arabia. *J Environ Sci Technol*, **9(2)**: 208-213.
- 14. Abdullah S, Ndikilar CE, Suleiman AB, Hafeez HY (2016)

- Assessment of heavy metals and radioactivity concentration in drinking water collected from local wells and Boreholes of Dotes Town, North West, Nigeria. *Journal of Environment Pollution and Human Health*, **4(1)**: 1–8.
- Sharma S, Duggal V, Srivastava AK, Mehra R (2017) Assessment of radiation dose from exposure to radon in drinking water from western Haryana, India. Int J Environ Res, 11: 141–147.
- Hatif KH, Muttaleb MK, Abass AH (2017) Health impact of Radon in water to Schools for City of Hilla – Iraq. Int J Chem Tech Res, 10(1): 415-421.
- Duggal V, Sharma S, Mehra R (2017) Radon levels in drinking water of Fatehabad district of Haryana, India. Appl Radiat Isot, 123: 36-40.
- Wiedner H, Lotter K, Karner P, Friedmann H, Maringer FJ (2018) Radon in drinking water: Comparison and evaluation of two ionization chamber activity measurement methods. Appl Radiat Isot, 134: 477-481.
- El-Tamera A (2011) Terrestrial gamma radioactivity level and their corresponding extent exposure of environmental samples from wade El Acuity protective area, as suit Upper Egypt. Radiate Protect Dosm, 145(4): 405–410.
- 20. WHO (2008) Guidelines for drinking-water quality. World health Organisation Publication, 1: 197-209.
- USEPA (2000) Radionuclides notice of data availability.
 Technical support document. United States environmental Protection Agency.
- Jankovic MM, Todorovic DJ, Todorovic NA, Nikolov J (2012) Natural radionuclides in drinking waters in Serbia. Appl Radiat Isot, 70: 2703–2710.
- Mayeen UK, Noor LMN, Nur SZ, Hasan AK, Khandoker A, Bradley DA, Zulkiflid MY, Adeeb H (2017) Radiation dose to the Malaysi an populace via the consumption of bottled mineral water. Radiation. *Physics and Chemistry*, 140: 173 –179.
- Kralik C, Friedrich M, Vojir F (2003) Natural radionuclides in bottled water in Austria. *Journal of Environmental Radioactivity*, 65: 233–241.
- Martina R, Matea R, Ljudmila B, Delko B, Petra P (2014) Radiological characterization of tap waters in Croatia and the age dependent dose assessment. *Chemosphere*, 111: 272–277.
- Kralik C, Friedrich M, Vojir F (2003) Natural radionuclides in bottled water in Austria. *Journal of Environmental Radioactivity*, 65: 233–241.
- Todorovic N, Jovana N, Sofija F, Istvan B, Dusan M, Miodrag K, Veskovic M (2012) Public exposure to radon in drinking water in SERBIA. *Applied Radiation and Isotopes*, 70: 543-549.
- Sola P, Srisuksawad K, Loaharojanaphand S, O-Manee A, Permnamtip V, Issarapan P, Thummagarun L (2013) Radon concentration in air, hot spring water, and bottled mineral water in one hot spring area in Thailand. *Journal of Radio*analytical and Nuclear Chemistry, 297, (2): 183–187.
- Jaqueline K, Sergei AP, Valeriy D, Janine NC, Marilson R, Camila GT, Flávia DC, Allan FP (2013) Measurements of

- radon and radium activity in bottled mineral water. International Nuclear Atlantic Conference INAC 2013 Recife, PE, Brazil, November 24-29, 2013 ASSOCIAÇÃO BRASILEI-RA DE ENERGIA NUCLEAR ABEN ISBN: 978-85-99141-05-2
- Fakhri Y, Mahvi AH, Langarizadeh G, Zandsalimi Y, Amirhajeloo LR, Kargosha M, Moradi M, Moradi B, Mirzaei M (2015) Effective Dose of Radon- 222 Bottled Water in Different Age Groups Humans: Bandar Abbas City, Iran. Global Journal of Health Science, 8(2): 64-71.
- Ali AA, Suha HK, Hussien AAM, Rua RM (2016) Radon levels in different types of bottled drinking water and carbonated drinks in Iraqi markets. Water Supply, 17 (1): 206-211
- Mohamed SS (2017) Measurement of radon-222 concentration in bottled natural mineral drinking water in Kuwait using the nuclear track detector (CR-39). Int J Physics, 5(6): 201-207.
- Hesham AY (2018) Assessment of the annual effective dose of bottled mineral waters using closed can technique. Journal of Advances in Physics, 14 (3): 5696-570.
- 34. Zvi D and Ofir T (2011) Variables with too-frequent values using a Kolmogorov–Smirnov test: A practical approach. *Computers & Industrial Engineering*, *61*: 1240–1244.
- Jesse F (2016) An exact Kolmogorov–Smirnov test for whether two finite populations are the same. Statistics and Probability Letters, 116: 65–71.
- Naoya O and Takashi S (2010) On the distributions of multivariate sample skewness. *Journal of Statistical Planning and Inference*, 140: 2809–2816.
- Ahmet C and Ugur T (2018) Skewness and kurtosis analysis for non-Gaussian Distributions. *Physica A*, 499: 325–334.
- Alexandra S and Winfried S (2017) Assessing skewness, kurtosis and normality in linear mixed models. J Multivariate Analysis. 161: 123–140.
- European Commission (1998) Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption. Official Journal L 330; 1998. p. 0032– 54. 05.12.
- Nisar A, Mohamad SJ, Mohammed SA (2015) Study of radon concentration and toxic elements in drinking and irrigated water and its implications in Sungai Petani, Kedah, Malaysia. *Journal of Radiation Research and Applied Science*, 8: 294-299.
- Faweya EB, Olowomofe OG, Akande HT, Adewumi TA (2018) Radon emanation and heavy-metals assessment of historical warm and cold springs in Nigeria using different matrices. Environmental Systems Research, 7-22.
- 42. European Commission (2005) Commission directive of defining requirements for the parameters of radioactivity for monitoring the quality of water for the council directive 98/83 of 3 Nov 1998 on the quality of water intended for human consumption, draft V3.0 29/11/2005.
- Food and Drug Administration (1998). Beverages— Requirements for Specific Standardized Beverages, 21 CFR 165.110 (b).